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FERTILIZERS For EARLY CABBAGE, TOMATOES, CUCUMBERS AND SWEET CORN

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FERTILIZERS FOR EARLY CABBAGE, TOMATOES, CUCUMBERS AND SWEET CORN

Fourth Report

JOHN BUSHNELL

For 32 years a fertilizer experiment with cabbage, tomatoes, cucumbers, and sweet corn was conducted at the Washington County Truck Crops Experiment Farm, located near Marietta, Ohio, in a district where early vegetables are grown intensively. The aim of the experiment was to aid local growers in their fertilizer practices.

Originally started by W. J. Green in 1915 as an exploratory test of fertilizers with and without manure, in 1921 it was continued by J. H. Gourley, who delegated the author to revise the plan in 1931. The results have been reported at intervals in three previous bulletins (3, 6, 7).*

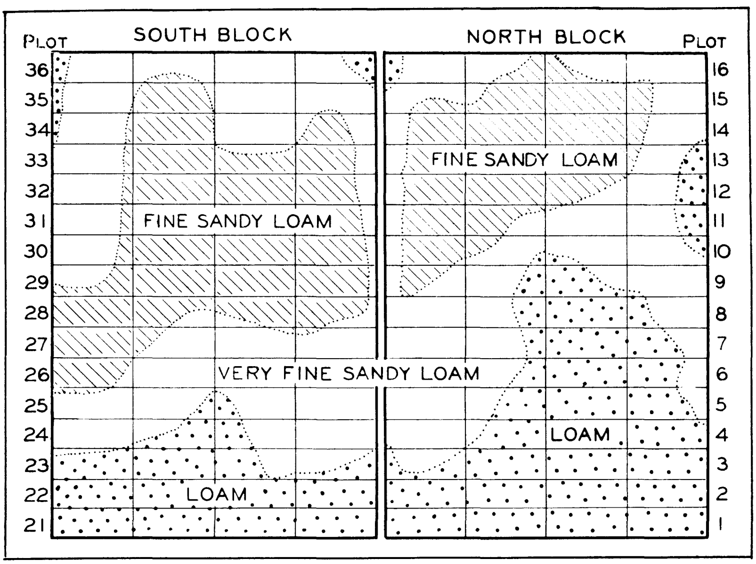

Fig 1.—Soil map of the experimental area

From survey made by G. W. Conrey and A. H. Paschall

* During the entire 32 years, the field operations were personally supervised by O. N. Riley, foreman, who also took all the records on yields. As the success of an experiment with vegetable crops depends largely upon the skill with which the crops are grown and the timeliness and accuracy with which the records are taken, credit for the results reported here should be shared with Mr. Riley.

PLAN AND PROCEDURES

The experimental field was on terrace soil of the Muskingum River, classified as Chenango. As indicated in Figure 1, the soil varied from loam to fine sandy loam.

The treatments were applied to plots 224 feet long and 20 feet wide, with 4-foot border strips intervening. The numbering of the plots is indicated in Figure 1. The four crops were planted across these plots in strips 54.5 feet wide, each crop on each plot occupying one-fortieth acre, giving a total of 128 individual plots.

When the experiment was planned in 1914, check plots were in vogue, and in the later revision the check-plot plan was retained.

Fertilizer and Manure Treatments

As may be seen from Table 1, the initial plan included ten manured plots, most of them given 16 tons per acre, four supplemented with fertilizer. The only complete fertilizer tested during the first 16 years was 4-10-4. The highest rate of application at the outset was 1250 pounds per acre, and during the second eight years, 1875 pounds. Except with tomatoes, this 4-10-4 did not give as good yields as were obtained from some of the manure treatments, hence in 1931 the plan was revised to test formulas with considerably higher proportions of nitrogen and of potash.

The scheme of the revised applications was to consider 1000 pounds of 8-12-8 as a base and to vary the proportion of nitrogen, phosphoric acid, and potash in turn. The check plots, previously unfertilized, were given the basic treatment supplemented with two side-dressings of sulfate of ammonia. In locating the other treatments, consideration was given to the preceding applications, which precluded a simple sequence in arrangement. Consequently, the scheme of treatments is not evident from a casual glance at Table 1, but will be found in later tables. Also included was a test of rate of application of 8-12-8 at 500 and 1500 pounds per acre.

The manure applications were reduced to eight tons per acre, except on three plots which were retained to see if long continued manuring at 16 tons per acre would maintain a higher level of productivity than could be obtained by fertilizers alone.

The initial plan included several liming tests. These were discontinued after 1930. Prior to planting in 1931, the previously unlimed plots were given eight tons per acre of ground limestone. No further lime was applied until 1942 when all plots were given a blanket application of two tons per acre.

During the first 16 years, fertilizers were mixed from nitrate of soda, 16 percent superphosphate, and 50 percent muriate of potash. During the second 16 years, nitrogen was supplied by sulfate of ammonia, and 20 percent grade of superphosphate was used. Manure

Table 1. Annual Applications of Manure and Fertilizer

Expressed in Amount Per Acre

Plot	Manure		Fertilizer broadcast before planting*						Side dressed sulfate of ammonia
	1915-1930	1931-1946	1915-22		1923-30		1931-46		1931-46
	Tons	Tons	Lb.	Formula	Lb.	Formula	Lb.	Formula	Lb
1 ck**							1000	8-12-8	380
2	16	8	400	0-16-0	800	0-16-0	1000	0-8-0	
3	16	8					1000	8-8-0	380
4 ck							1000	8-12-8	380
5	16	16					1000	8-8-0	570
6			1250	4-10-4	1250	4-10-4	1500	8-12-8	570
7 ck							1000	8-12-8	380
8			625	4-10-4	1875	4-10-4	1000	8-12-24	380
9			625	4-10-0	1250	4-10-0	1000	8-12-16	380
10 ck							1000	8-12-8	380
11			400	0-16-0	800	0-16-0	1000	8-12-0	380
12			145	18-0-0	260	21-0-0	1000	8-12-8	570
13 ck							1000	8-12-8	380
14			160	16-0-0	320	16-0-0	1000	8-12-8	190
15			160	16-0-0	320	16-0-0	1000	8-12-8	
16 ck							1000	8-12-8	380
21	8	8			1250	4-10-4	1000	8-8-16	
22 ck							1000	8-12-8	380
23	16	8	625	4-10-0	625	4-10-0	1000	8-24-0	
24	16	8					1000	8-16-0	
25	16	8					1000	8-0-0	
26	16	8	625	4-10-0	625	4-10-0	1000	8-8-0	
27	16	16							
28	16	16	400	0-16-0	400	0-16-0	1000	8-6-4	
29 ck							1000	8-12-8	380
30			625	4-10-4	625	4-10-4	500	8-12-8	
31			625	4-10-4	625	4-10-4	1000	8-0-8	380
32 ck							1000	8-12-8	380
33									
34			625	4-10-0	625	4-10-0	1000	8-20-8	380
35 ck							1000	8-12-8	380
36			400	0-16-0	400	0-16-0	1000	0-12-8	

*Mixed fertilizers expressed in formulas that illustrate the differences in the fertilizers compared. Actually, the equivalent amounts of fertilizer constituents were mixed and applied without filler.

** "ck" indicates check plots unfertilized through 1930, thereafter uniformly fertilized.

came from the team of horses kept on the farm and was spread during the winter.

For cabbage, the fertilizer was broadcast and disked in late March shortly before setting the plants. For the other crops it was similarly applied in late April. The side dressings of nitrogen fertilizer were made at times deemed most suitable for the individual crops.

Method of Handling the Crops and Reporting the Data

All four crops have been grown every year and in regular rotation, except that cucumbers were discontinued during the acute labor shortage of 1944-46. The area they should have occupied was not fertilized and was planted to soybeans, which were then plowed down. Until 1941 the crop rotation was: tomatoes, cabbage, cucumbers, and sweet corn. Then it was deemed preferable to have tomatoes follow cabbage, and the position of cucumbers and tomatoes was switched.

The varieties of the last eight years and the planting distances were:

Tomatoes: Stokesdale, plants set 50 by 24 inches
Cabbage: Golden Acre, yellow-resistant strain, set 36 by 14 inches.
Cucumbers: Early Fortune, hills 72 by 34 inches
Sweet Corn: Marcross, hills 36 by 34 inches

The cultural methods were those currently followed in the district. Tomato plants were tied to stakes and pruned to single stems. Crop residues were disked in. After cabbage, which was harvested by mid-July, soybeans were grown for cover crop, disked down in September, and followed by winter barley. Barley, for a winter crop, was sown directly after the other three crops. No fertilizer was applied to it.

The only data taken regularly year after year on all of the crops have been the yields of marketable produce. The standard as to what was "marketable," however, fluctuated some with the changes in local marketing standards.

Causes of Variation in Yields

As a whole, the three and one-half acre block proved well suited for a fertilizer experiment. Although the soil varies from loam to fine sandy loam (Figure 1) the growth of plants has not been noticeably affected by this difference in texture. In dry seasons, however, the loam has produced somewhat higher yields. The field is generally level, but slopes downward slightly at the south corners.

The subsoil is sandy affording excellent natural drainage. Prolonged heavy rains have never caused noticeable injury. On the other hand, during prolonged dry periods the plants suffered. In the very dry season of 1930 all crops failed, and in 1936 the sweet corn failed.

Damage from insects and diseases has at times been serious, particularly on cucumbers. In some seasons, cucumber beetles appeared to move in from the west, infesting plots 16 and 36 most seriously. In recent years, sweet corn has been more or less infested with corn borer and ear worm. For a few years, beginning about 1931, tomatoes were also infested with the corn ear worm. During the last eight years, however, tomatoes and cabbage have been exceptionally free from insects or diseases. Their yields have averaged higher than at any previous period.

Use of check plots. Except for a solid block of six manured plots, every third plot was designated at the outset as a check. For 16 years these were unfertilized; after that they were liberally and uniformly fertilized. To compare the yield of one treatment with another located some distance away, comparisons with the check plots are advantageous. These comparisons are drawn from the increase or decrease in yield of each treatment above or below its adjacent checks. In making this calculation it has been assumed that the soil and other conditions varied progressively from one check to the next. Thus, if check plots 1 and 4 yielded 500 and 530 pounds, respectively, it was assumed that plots 2 and 3 would have yielded 510 and 520 pounds, respectively, if they had had the same treatment as the checks. The actual yields of plots 2 and 3 were then compared with these calculated check values.

The calculated increases or decreases are listed with the average yields in most of the tables that follow.

Estimate of the difference in yield required for statistical significance as the fertilizer treatments are not replicated, an analysis of the variance cannot be made. To derive an estimate of the difference in yield required for significance, the variance of the annual yield of the check plots of the north block has been made for the two eight-year periods that they have been fertilized. The least significant differences at the five percent level, thus derived, are included in most of the tables of yields.

SOIL CONDITIONS AS SHOWN BY LABORATORY TESTS

At the outset in 1915, no chemical analyses were made of the soil, nor were samples preserved. In order to obtain an estimate of the initial fertility, samples were taken in 1938 from uncropped roadways adjoining the experimental area. The fertility indicated by these tests is moderate for vegetable soils:

Soil reaction: pH 5.0 to 5.4
Available phosphorus, by Truog's method (15): 50 to 150 pounds per acre.
Exchangeable potassium, by Thornton's method (14): 100 to 200 pounds per acre.

In this connection some inquiries were made as to the previous treatment of the land. From the county records of property transfers and from statements of neighbors whose forefathers were pioneers, it appears that the land was cleared from forest between 1840 and 1850 and operated as part of a successful general farm until 1908. Then for five years it was rented for vegetable cropping to tenants who probably applied neither manure nor fertilizer, for their crops were said to have been poor. Consequently, when acquired for experimental purposes the land was reputed to be in a low state of fertility compared with successful neighboring vegetable farms.

Soil reaction. Samples of soil from each of the experimental plots were first collected in the fall of 1930, 16 years after the experiment was initiated. Thereafter, samples were taken regularly at eight-year intervals. The pH determinations of these samples are listed in Table 2.

Most of the plots were given a ton of ground limestone per acre each winter during the first 16 years. In the fall of 1930 soil from these plots ranged in pH from 6.6 to 7.2. Soil from the unlimed plots (22, 23, 27, 29, 32 and 35) ranged from 4.9 to 5.8.

The unlimed plots were then limed in the spring of 1931 to bring their reaction close to that of adjacent plots. At the same time a change was made to sulfate of ammonia, an acid-forming fertilizer, as the carrier of nitrogen. The plan also called for applying it to the check plots at the high rate of 760 pounds per acre, and at still higher rates to plots 6 and 12. Through an oversight, no provision was made to compensate for the resulting acidity. By the end of 16 years, the pH of the check plots ranged from 5.2 to 6.0 and that of plots 6 and 12 was 4.5 and 5.0 respectively. It was only on plot 6 with a final pH of 4.5, however, that the acidity appeared to be detrimental to all four crops.

Available phosphorus. After the plan was revised in the spring of 1931 the crops on previously unfertilized plots showed phosphate deficiency for several years. On the other hand, where phosphate was omitted from previously fertilized plot 31, the residue proved to be sufficient for several years. Attention consequently was turned to the amount of available phosphorus in the soil. The data are included in Table 2.

EFFECT OF PRECEDING TREATMENTS ON CROPS FOLLOWING REVISION OF THE PLAN IN 1931

Inadequacy of fertilizer on previously unfertilized soil. When the check plots were first fertilized the application of 1000 pounds per acre of 8-12-8, supplemented with two side dressings of sulfate of ammonia, failed to produce as good crops as were obtained on previously fertilized plots. No previously fertilized plot, however, was getting applications identical with the checks, so a direct comparison cannot be made. A number of combinations with the same amount of nitrogen were used, such as those listed in Table 3. For brevity, the yields on these plots during the first four years are given here simply in terms of their average increases over the checks. It was only with

Table 2. Reaction and Available Phosphorus of the Soil at Eight-Year Intervals, Beginning 1930

	Soil reaction, pH			Available phosphorus pounds per acre*		
Plot	1930	1938	1946	1930	1938	1946
North Block						
1 ck**	6.8	6.6	5.6	177	230	294
2	6.6	7 0	7.1	484	410	580
3	6.7	6.4	6.5	237	260	335
4 ck	6 9	6.3	5.4	166	200	280
5	6.7	6 4	5.4	220	330	370
6	6.8	6.1	4.5	388	340	390
7 ck	6 9	6 4	5.5	181	260	340
8	6.8	6.4	5.5	330	330	395
9	6.8	6.2	5.5	318	250	373
10 ck	7.0	6 3	5.4	157	200	288
11	6.9	6.3	5 2	284	220	293
12	7.0	6 1	5.0	130	170	249
13 ck	7.0	6 4	5.2	128	170	218
14	7.2	6.7	5 8	137	190	226
15	7.0	7.0	6 3	129	200	274
16 ck	7.1	6 7	5.5	121	160	225
South Block						
21	7.0	6.8	6.3	196	330	422
22 ck	4.9	6.5	5.4	67	210	312
23	5.2	6.9	6.3	172	480	730
24	5.4	7.2	6.5	70	250	490
25	7.0	7.2	6.6	238	230	239
26	6.7	7.3	6.7	300	320	320
27	5.8	7.7	7.2	127	270	278
28	6.8	7.4	6.6	308	360	280
29 ck	5.1	7.1	5.4	46	180	199
30	5.5	7.3	6.9	86	200	194
31	7.1	7.2	5.9	162	120	74
32 ck	5.5	7.4	5.9	40	140	159
33	7.2	7.6	7.3	124	90	117
34	7.0	7.0	6.2	220	300	380
35 ck	5.3	7.2	6.0	50	200	264
36	7.1	7.4	7.2	232	270	432

*Analyzed by Truog's method (15). Samples of 1930 and 1946 were analyzed by R. M. Harder in Truog's laboratory at the Department of Soils, Wisconsin Agricultural Experiment Station.

** "ck" designates check plots uniformly treated, except that up to 1931 those in the North block were limed and those in the South block were not.

cabbage that these increases were of statistical significance, but the fact that some increase occurred with all crops, and on all the plots listed, is fairly good evidence that the check plots were not supplying enough fertility.

That phosphate was the nutrient most deficient in the check plots is indicated in Table 3 by the data of plot 34. Plot 34 had received no potash prior to 1931. It differed from checks in the nitrogen and phosphate received previously, and in the extra phosphate since 1931. Assuming that the previously applied nitrogen had no carry-over effect, the increases listed in Table 3 must be ascribed to the additional phosphate. Stated conversely, the increases of plot 34 are evidence that the check plots did not have ample phosphate during the first four years that they were fertilized.

Table 3. Data Illustrating the Effect of Previous Treatments on the Average Yields During the Four Years of 1931-34

	Fertilizer applied during 1915-30					Least significant difference
	None	4-10-0		4-10-4		
	Fertilizer applied beginning 1931, at rate of 1000 pounds per acre*					
	Checks 8-12-8	Plot 34 8-20-8	Plot 9 8-12-16	Plot 31 8-0-8	Plot 8 8-12-24	
	Av. yield per acre	Average annual increase over checks, pounds per acre				
Cabbage	21,993	3,200	2,760	3,930	2,580	2,156
Tomatoes	7,205	900	805	1,082	1,035	1,178
Cucumbers	4,626	285	1,118	720	840	1,304
Sweet Corn	5,162	30	330	110	10	1,028

*All these plots, including the checks, were also given two side dressings of sulfate of ammonia on all the crops.

Similarly to determine if potash was also somewhat deficient on the check plots, the increases shown by plots 31 and 8, where complete fertilizer had been applied previously, may be compared with the increases of plot 34, which, like the checks, previously received no potash. The differences are relatively small and not entirely consistent, indicating that eight percent of potash in the fertilizer applied to soil, which had previously received none, was very nearly ample for yields of the magnitude obtained during these years.

Maintenance of yields by residual phosphate. In contrast to the results on the previously unfertilized check plots, it was surprising to find that when phosphate was omitted from the fertilizer of plot 31 (Table 3) the crops showed no indication of deficiency for the first four years. Apparently the soil had accumulated a reserve of available phosphate sufficient to supply the crops' needs. During the preceding 16 years only 64 pounds of phosphoric acid per acre had been applied annually, a relatively small amount compared with common fertilizer practice in vegetable production.

To determine if plot 31 was exceptional in its content of available phosphorus, the samples collected in the fall of 1930 were analyzed by Truog's method. As shown in Table 2, plot 31 was found to have 180 pounds per acre of available phosphorus, and was not out of line with the other plots that had been similarly fertilized, or those that had been manured. Moreover, 180 pounds per acre is not considered to be an exceptionally large amount of available phosphorus. Yet it sufficed to supply the crops grown here for at least four years.

EXPERIMENTS ELSEWHERE DEMONSTRATING THAT PHOSPHATE ACCUMULATED IN THE SOIL MAY SUFFICE FOR VEGETABLE CROPS

In view of the fact that in the revised plan of 1931 phosphate was omitted from only one plot, and consequently the surprising maintenance of yields by the residual phosphate was demonstrated by only this one plot, it seems advisable, before making recommendations along this line, to point out that similar results have been reported from several other experiments in eastern states.

As early as 1933, Odland and Crandall in Rhode Island (12) from an eight-year experiment with cabbage, obtained slightly larger average yields from 8-0-8 than from 8-8-8. They did not give any chemical data on their soil.

Since then, most of the experiments of interest have been with potatoes, instead of with the crops grown here. Potatoes, however, are recognized as a crop requiring a high level of soil fertility—large amounts of fertilizer are commonly applied to them—consequently the results with potatoes may well apply to other vegetable crops.

Morgan and Jacobson, in Connecticut (11), described a well replicated experiment in which small proportions of phosphate in the fertilizer gave no increase in yield, and large proportions induced significant decreases. The soil of their no-phosphate plots averaged 196 pounds of available phosphorus per acre. They used Truog's method of analysis, which was also used by all the others mentioned here whose experiments dealt with potatoes. In Ohio, on soil with 200 pounds of available phosphorus, Bushnell (5) found the inclusion of phosphate in the fertilizer increased the yield only two bushels per acre.

A unique exploration of the fertilizer needs of potato soils was conducted jointly in 1945 by the experiment stations of Maine and of North Carolina, (9). Samples from a large number of growers' fields were analyzed at the outset, then a series of fields ranging widely in available phosphorus was selected for fertilizer experiments in each state. The fertilizer treatments in each selected field were replicated four or five times, and the amount of phosphoric acid in the mixtures was stepped up by 40-pound increments from none to 160 or to 200 pounds per acre. In both states, some of the fields gave little or no response to phosphate in the fertilizer. In North Carolina three of the selected fields were in this class, and all three had 310 pounds or more of available phosphorus. The other three had 180 pounds or less, and gave marked response. In Maine the experiments were conducted on eleven fields. Four, with 158 pounds or more of available phosphorus, gave no significant increases in yield from the inclusion of phosphate in the fertilizer. The other seven had 153 pounds or less, and all but one gave significant increases from the applied phosphate.*

As a whole, these experiments with potatoes convincingly demonstrate that soils may contain an accumulated reserve of available phosphorus sufficient to maintain yields when phosphate is omitted from the fertilizer. Although none were planned to determine the threshold at which the amount suffices, in all cases soil with 200 pounds per acre of available phosphorus had an ample reserve.

Working with tomatoes, and aiming to determine the threshold Arnold, in Illinois (1), concluded from rather meager data that Lisbon silt loam contained ample available phosphorus when it had 290 pounds per acre determined by Bray's method (2). Bray's method of extraction removes some adsorbed, as well as acid-soluble, phosphorus, and consequently indicates more as being "available" than does Truog's procedure. To compare his findings with those obtained here, Arnold also analyzed samples sent to him from plots of interest. The soil from plot 31, which in 1930 was above the threshold, and showed 180 pounds by Truog's method of analysis, showed 231 pounds by Bray's. In this instance, Bray's procedure extracted about 30 percent more. With other samples the difference ranged as high as 60 percent. Arnold's threshold soils were not analyzed by Truog's method, but if Arnold's value of 290 pounds is reduced by 30 percent as an estimate of what it would show if so analyzed, it falls in line with the conclusion that the threshold for tomatoes is near 200 pounds of

* The data in this report are given in terms of phosphoric acid (P_2O_5). For convenient comparison with work elsewhere, they are here converted to terms of phosphorus (P) by dividing by 2.289.

available phosphorus per acre as determined by Truog's method.

Incidentally, the divergence in threshold values as found in Ohio and in Illinois should not discredit the concept that soils may contain ample phosphate; similar divergence appeared in the data on potatoes at different localities. It should rather be taken as indication that the threshold actually varies from one soil to another. Moreover, as well exemplified in the data of this experiment, crops differ in their capacity to obtain their needed phosphate from the soil. Tomatoes required as high a level as any of the crops. Hence, if a soil has enough phosphorus available for tomatoes, it would be expected to have enough, or more than enough, for the other crops.

A broad recommendation, then, concerning the point at which phosphate might be omitted from fertilizer, should, at this stage of our knowledge, name the highest threshold value that has been indicated experimentally. For potatoes, the experimental data are in good agreement in pointing to a safe threshold of 200 pounds of available phosphorus per acre, when determined by Truog's method. For tomatoes, it is not well established, but also appears to be near 200 pounds.

AVAILABLE PHOSPHORUS IN GROWERS' SOILS

To determine whether their soils were at a similar level of available phosphorus to that of this experiment, eight growers in Washington County in 1942 collected samples from 34 fields and had them analyzed by E. L. Krause, Professor of Chemistry at Marietta College, using Truog's method. Data on the previous treatments were not submitted with the samples. A wide range was found, as shown by the following grouping:*

Available phosphorus per acre	Number of samples
Less than 100 pounds	5
100 to 200 pounds	9
201 to 300 pounds	5
301 to 400 pounds	3
401 to 500 pounds	6
Over 500 pounds	6

* The author is indebted to Professor Krause and to the growers for permission to publish these

As a whole, the range in these growers' soils was similar to that found in the experimental plots as listed in Table 2. Of special interest is the fact that of the 34 samples, 20 contained more than 200 pounds of available phosphorus per acre.

At the time these analyses were made it was suspected that the soil of this district must have a higher level of available phosphorus than other vegetable districts of eastern states. An extensive survey, in 1945, however, of 368 potato fields located on the Atlantic coastal plain, from North Carolina through Long Island, showed a similar

Table 4. Average Annual Yield, Fourth 8 Years, 1939 - 1946

Plot	Treatment per Acre				Average yield per acre and increase or decrease compared with uniformly fertilized check plots								
					Cabbage		Tomatoes		Cucumbers**		Sweet Corn		
	Manure Tons	Fertilizer Lb.	Fertilizer Formula	Side Dressings* No.	Yield Lb.	Increase or Decrease Lb.	Yield Lb.	Increase or Decrease Lb.	Yield Lb.	Increase or Decrease Lb.	Yield Lb.	Increase or Decrease Lb.	Plot
1 ck		1,000	8-12-8	2	29,240		13,460		14,200		5,495		1
2	8	1,000	0-8-0		27,090	—3,392	14,340	637	18,748	3,736	5,220	— 401	2
3	8	1,000	8-8-0	2	34,860	3,137	14,655	708	17,696	1,872	6,710	962	3
4 ck		1,000	8-12-8	2	32,965		14,190		16,636		5,875		4
5	16	1,000	8-8-0	3	34,480	1,778	15,485	1,498	17,368	1,040	7,015	1,135	5
6		1,500	8-12-8	2*	30,905	—1,533	13,400	— 383	16,260	240	5,965	80	6
7 ck		1,000	8-12-8	2	32,175		13,580		15,712		5,890		7
8		1,000	8-12-24	2	32,025	— 140	13,678	153	15,960	190	5,890	— 68	8
9		1,000	8-12-16	2	33,610	1,455	13,830	360	16,272	443	6,360	333	9
10 ck		1,000	8-12-8	2	32,145		13,415		15,888		6,095		10
11		1,000	8-12-0	2	22,320	—9,200	11,950	—1,367	11,564	—4,129	5,535	— 947	11
12		1,000	8-12-8	3	28,585	—2,310	13,100	— 118	15,864	365	6,835	— 34	12
13 ck		1,000	8-12-8	2	30,270		13,120		15,304		7,255		13
14		1,000	8-12-8	1	30.945	553	13,045	12	14,688	1,176	6,810	— 400	14
15		1,000	8-12-8	0	28,640	—1,873	13,698	751	14,152	2,432	6,670	— 495	15
16 ck		1,000	8-12-8	2	30,635		12,860		9,928		7,120		16
21	8	1,000	8-8-16		29,355	—1,510	12,765	375	14,184	— 28	5,655	375	21
22 ck		1,000	8-12-8	2	30,865		12,390		14,212		5,280		22
23	8	1,000	8-24-0		31,770	834	13,588	1,382	16,904	2,682	6,065	732	23
24	8	1,000	8-16-0		32,330	1,324	13,290	1,268	18,272	4,041	6,345	959	24
25	8	1,000	8-0-0		30,775	— 302	13,253	1,416	17,504	3,263	6,535	1,096	25
26	8	1,000	8-8-0		31,965	816	13,275	1,622	17,464	3,213	6,805	1,314	26
27	16				25,385	—5,834	11,960	491	16,912	2,651	6,845	1,301	27
28	16	1,000	8-6-4		34,260	2,971	13,178	1,894	17,688	3,418	6,670	1,073	28
29 ck		1,000	8-12-8	2	31,360		11,100		14,280		5,650		29
30		500	8-12-8		23,540	—7,158	10,708	— 677	13,264	— 576	3,760	—1,860	30
31		1,000	8-0-8	2	28,340	—1,696	10,965	— 705	10,944	—2,456	4,545	—1,045	31
32 ck		1,000	8-12-8	2	29,375		11,955		12,960		5,560		32
33					10,850	—18,792	8,095	—3,883	7,784	—4,605	2,830	—2,453	33
34		1,000	8-20-8	2	30,725	817	12,133	131	13,952	2,133	4,800	— 207	34
35 ck		1,000	8-12-8	2	30,175		12,025		11,248		4,730		35
36		1,000	0-12-8		14,315	—15,860	9,618	—2,407	8,776	—2,472	2,710	—2,020	36
		Least significant difference				2,709		1,352		2,078		1,312	

* Each side dressing 190 pounds per acre of sulfate of ammonia, except on plot 6 where it was at the rate of 285 pounds

** Cucumbers were grown for only 5 years; 1939-1943.

range, (13). More than half of these potato soils were found to have over 200 pounds per acre of available phosphorus.

ESTIMATE OF A MAINTENANCE APPLICATION OF PHOSPHATE

From a practical viewpoint, the vegetable grower who finds that his soil contains over 200 pounds per acre of available phosphate is not likely to be as much interested in omitting phosphate from his fertilizer as in including enough to maintain the amount in the soil at a high level. Data on this phase of the problem has not been found in the literature.

Some estimates of a maintenance application, however, can be drawn from this experiment. First, it might be restated that the annual application of fertilizer with 64 pounds of phosphoric acid per acre during the first 16 years resulted in an accumulation in the soil sufficient to support the crops of plot 31 for at least the following four years. Evidently, then, 64 pounds of phosphoric acid was somewhat more than a maintenance amount. Second, the rate of depletion of the available phosphorus in plot 31 after 1931 may be noted by referring back to Table 2. Starting at 180 pounds in 1931 the available phosphorus dropped to 120 pounds by 1939. The decrease of 60 pounds in eight years was 7.5 pounds per year. Expressed as phosphoric acid, this was equivalent to 17.5 pounds per acre. Again referring to Table 2, one may note that on manured plot 25 the available phosphorus was 238 pounds per acre in 1930 and 16 years later stood at 239 pounds. This plot was given eight tons of manure per acre annually, during these years with no supplementary phosphate. The manure was not analyzed, but judging from the fact that manure is commonly considered to supply three to four pounds of phosphoric acid per ton, the annual amount applied to the manure was something like 24 to 32 pounds per acre.

Accordingly, an annual maintenance application would be expected to be something between 17.5 and 32 pounds of phosphoric acid per acre. In view of the meager data, a tentative recommendation would be to apply at least 30 pounds, and perhaps 40 pounds per acre, to insure maintaining an adequate supply. Although these are small amounts compared to current practice, they are still much larger than the amounts removed by the crops (Data given later in Table 16). Specific recommendations in line with this deduction are included in the discussions that follow.

AVERAGE YIELDS OF 1939-1946

As a convenient method of presenting records extending over a long period of years, the policy has been adopted of averaging them into eight-year periods. Eight years includes two cycles of the crop rotation.

The average annual yields for the first three eight-year periods were presented in the preceding report (3). The more significant data from these years will be found in the tabulation of the results of the individual crops that follows.

The average yields for the fourth eight years, listed in Table 4, also appear in the following tabulations of the individual crops. They are presented in their entirety here for the benefit of critical readers who may be interested in yields of certain check plots that are not listed elsewhere.

In general the yields of cabbage and tomatoes during the fourth eight years were higher than at any preceding period, while those of cucumbers and sweet corn were below normal.

Table 5. Yield of Cabbage on Limed Plots, 1915-1929

Plot	Annual Application*	Fertilizer per acre, lb.		Average annual yield per acre, lb.		Increase over unfertilized checks, lb.	
		1915-22	1923-29	1915-22	1923-29	1915-22	1923-29
	North Block, check plots limed the same as all others						
15	Nitrate of soda	160	480	16,070	23,263	1,985	4,558
12	Sulfate of ammonia	†	360	16,465	22,731	1,412	3,453
11	Superphosphate, 16%	400	800	16,960	20,863	1,728	1,129
9	4-10-0	625	1,250	19,077	26,863	3,496	6,465
8	4-10-4	625	1,875	19,225	30,286	3,471	9,678
6	4-10-4	1,250	1,250	20,900	28,463	4,875	7,688
3	Manure			20,005	24,263	3,886	4,113
2	Manure and superphos	400	800	20,907	24,360	4,896	4,750
	South Block, check plots not limed						
33	Lime only			15,990	15,571	2,733	3,046
36	Superphosphate, 16%	400	400	16,220	17,400	3,675	5,012
34	4-10-0	625	625	19,960	22,731	7,060	10,251
31	4-10-4	625	625	20,660	23,931	6,803	10,663
25	Manure			22,325	26,794	8,124	12,712
28	Manure and superphos.	400	400	22,755	26,583	8,554	12,065
26	Manure and 4-10-0	625	625	24,930	29,960	10,729	15,733

* All manure applications at rate of 16 tons per acre.

† Mixture of sulfate of ammonia, 65 pounds, and nitrate of soda, 80 pounds per acre.

RESULTS FROM THE INDIVIDUAL CROPS

The primary aim in the discussion of the individual crops is to derive fertilizer recommendations applicable to soil of the type used. In interpreting the data, when there is doubt as to whether an amount is adequate, preference is given to a larger amount. This policy of deriving recommendations is adopted with the assumption that growers prefer to apply an excess of fertilizer, simply as a matter of insurance, if they have any feeling that a smaller amount might not prove adequate. The reader can, of course, draw somewhat different deductions from the data if he so chooses.

Results with Cabbage

Fertilizer without manure. Data of the early years (Table 5) demonstrated that a complete fertilizer was needed by cabbage. The only formula tested, however, was 4-10-4. Application at the high rate of 1875 pounds per acre to plot 8 during 1923-29, produced larger yields than 1250 pounds on plot 6.

In the revised plan (Table 6), the basic application of 1000 pounds of 8-12-8 supplied 80 pounds of nitrogen per acre—approximately the same as the 75 pounds previously supplied in 1875 pounds of 4-10-4. Additional nitrogen applied as side dressing of sulfate of ammonia on plot 14 increased the yield over plot 15. Further side dressings were mostly ineffective—examination of the yearly records showed that they were of benefit in only four of the 16 years.

In the phosphate series, the residue in plot 31 sustained the yield of cabbage through 1938, then evidence of deficiency appeared. On the other hand, the 8-12-8 on previously unfertilized check plot 32 proved insufficient during 1931-38; not until 1941 did its yield equal that of plot 34. Incidentally, it might be added that the soil of plot 32 in 1938 had 140 pounds of available phosphorus per acre. With this amount present in the soil, it was rather surprising to find that 1000 pounds of 8-12-8 per acre was not entirely ample.

In the potash series, plot 9 with 8-12-16 produced slightly larger yields than did 8-12-8 on the checks. Although not statistically significant, the difference is an indication the eight percent of potash was not quite sufficient. The question might be raised as to why the 24 percent of plot 8 was not equally beneficial during 1939-46. This was not specially studied, but there is the possibility that it resulted in an excess of potash in the soil which interfered with the absorption of calcium by the roots during these years when the pH was dropping from 6.2 to 5.5.

In the rate-of-application series at the bottom of Table 6, the 1500 pounds per acre on plot 6 is of special interest because it was the highest yielding of the unmanured plots as long as its pH was above 6.0. Because well fertilized prior to 1931, its good yields of 1931-38

Table 6. Yield of Cabbage, 1931-1946

Fertilizer applied before planting at rate of 1000 pounds per acre, side dressings of sulfate of ammonia at rate of 190 pounds per acre

Plot	Fertilizer Before Planting Formula	Fertilizer Side Dressings No.	Average annual yield per acre 1931-38 Lb.	Average annual yield per acre 1939-46 Lb.	Increase or decrease compared with uniformly fertilized check plots 1931-38 Lb.	Increase or decrease compared with uniformly fertilized check plots 1939-46 Lb.
Fertilizers without Manure						
			Nitrogen Series			
36	0-12-8		13,490	14,315	—8,280	—15,860
15	8-12-8		21,725	28,640	—2,328	— 1,874
14	8-12-8	1	23,675	30,945	— 702	554
13 ck.	8-12-8	2	24,700	30,270		
12	8-12-8	3	24,350	28,585*	— 153	—2,310*
			Phosphate Series			
31	8-0-8	2	25,120	28,340	1,957	— 1,696
32 ck.	8-12-8	2	22,215	29,375		
34	8-20-8	2	24,190	30,725	2,272	816
			Potash Series			
11	8-12-0	2	17,815	22,320	—6,492	— 9,200
10 ck.	8-12-8	2	24,110	32,145		
9	8-12-16	2	26,250	33,610	1,982	1,455
8	8-12-24	2	26,120	32,025	1,693	— 140
Fertilizer with 8 tons of Manure per acre						
			Nitrogen Series			
2	0-8-0		21,755	27,090	—2,552	— 3,391
26	8-8-0		27,365	31,965	2,603	817
3	8-8-0	2	26,840	34,860	2,102	3,136
			Phosphate Series			
25	8-0-0		25,710	30,775	1,047	— 302
26	8-8-0		27,365	31,965	2,603	817
24	8-16-0		26,195	32,330	1,631	1,325
23	8-24-0		26,055	31,770	1,591	835
Fertilizer with 16 tons of Manure per acre						
27	none		23,015	25,385	—1,846	— 5,835
28	8-6-4		28,615	34,260	3,654	2,970
5	8-8-0	2	27,680	34,480	2,705	1,778
Rate of Application of 8-12-8, without Manure						
	Lb. per acre					
33	none		6,990	10,850	—15,077	—18,791
30	500		20,975	23,540	— 3,137	— 7,159
29 ck.	1000	2	25,060	31,360		
6	1500	2†	27,570	30,905*	2,790	—1,533*
Least significant difference					1,740	2,709

* Decline in yield presumably due to acidity of soil.

† Side dressings 285 lb. per acre.

are better compared with plots 9 and 34 than with the checks. Compared with plot 9, the yield on plot 6 was significantly higher. To picture the comparison, the treatment of plot 6 might be expressed as 1000 pounds per acre of 12-18-12, that of plot 9 being 8-12-16. Assuming that both plots, being previously fertilized, had ample phosphate, and noting that plot 9 got more potash, one must attribute the higher yield on plot 6 to its larger amount of nitrogen. The larger amount of nitrogen, however, was not restricted to the initial fertilizer; the side dressings were also 50 percent larger than on any other plots. Judging from growth and appearance, the plants seemed to benefit from the additional nitrogen of the first side dressing rather than from the additional in the initial fertilizer. Consequently, the tentative conclusion is that a side dressing of about 300 pounds of sulfate of ammonia is likely to prove better than 200 pounds per acre when applied to early cabbage shortly after the plants have resumed growth in the field.

Another deduction from the good yield of plot 6 during 1931-38 is that its 1500 pounds per acre of 8-12-8 supplied ample potash, the amount being 120 pounds per acre.

The combined recommendation, then, for early cabbage on soil that has been well fertilized previously, properly limed, and has somewhat more than 140 pounds per acre of readily available phosphorus (By Truog's method of determination) is 1000 pounds per acre of 8-12-12, supplemented with one side dressing of about 300 pounds per acre of sulfate of ammonia, or its equivalent of some other nitrogen carrier. In occasional wet years a second side dressing may also be needed. For soil with less available phosphorus the initial application should be equivalent to 1000 pounds of 8-20-12, while on soil with over 200 pounds of available phosphorus the proportion of phosphoric acid might be reduced to make an 8-4-12, as suggested in preceding pages.

None of these formulas are among the currently approved grades of fertilizers in Ohio. Suggestions on using approved grades, with the supplements needed, are therefore made later in the summary of the recommendations.

Fertilizers with Manure. During the early years (Table 5) superphosphate supplementing manure on plots 2 and 28 induced small increases over plots 3 and 25 in the average yields of 1915-22, but not during 1923-29. The inclusion of nitrogen on plot 26 gave conspicuous and consistent increases. Presumably manure did not nitrify rapidly enough during cool spring weather to supply the needs of early cabbage.

With manure applications reduced to eight tons per acre after 1930 (Table 6), all plots, except plot 2, were given a large application of 80 pounds of nitrogen per acre. The omission of this nitrogen very significantly reduced the yield. Likewise, where 16 tons of manure continued to be applied, the omission of all fertilizer from plot 27 resulted in much lower yield than produced by plots 5 or 28. Side dressings of sulfate of ammoria on plot 3 were of no benefit during 1931-38, but in the seasons of high yields of 1939-46 they gave increases in six of the eight seasons. On the other hand, with 16 tons of manure per acre the side dressings of plot 5 were ineffective.

In the phosphate series, the inclusion of phosphate on plot 26 gave small increases over plot 25. Plot 25 had not had any previously. The increases from the 80 pounds of phosphoric acid per acre on plot 26 were, however, no larger than resulted from 64 pounds per acre on plot 9 doing the earlier years.

As a whole, nitrogen proved to be the important fertilizer needed with manure for early cabbage. Not less than 80 pounds per acre, such as supplied by 380 pounds of sulfate of ammonia, can be advised from the data here. With eight tons of manure per acre, additional nitrogen applied as side dressing may also be needed to insure bumper crops. If the land has not been phosphated previously, superphosphate supplying about 64 pounds of phosphoric acid per acre is also to be recommended.

Results with Tomatoes

Fertilizers without manure. During the first eight years of the experiment (Table 7) 1250 pounds of 4-10-4 per acre on plot 6 gave bigger yields of tomatoes than were obtained from 625 pounds on plot 8. When the rate was raised to 1875 pounds on plot 8, however, it did not prove better than the continued application of 1250 pounds per acre on plot 6. To compare these results with those of the following years, it should be kept in mind that 1250 pounds of 4-10-4 supplied only 50 pounds per acre of nitrogen and of potash.

Following the change in plan of treatments (Table 8), the omission of nitrogen from plot 36 distinctly reduced the yield. Side dressings of sulfate of ammonia on plots 12, 13, and 14 proved ineffective—reducing the yield more often than increasing it.

In the phosphate series its omission from plot 31 resulted in some indications of deficiency after 1934. On previously unfertilized plot 10 the application of 8-12-8 failed to give as good yields as produced by 8-20-8 on plot 34 for five years, but thereafter the difference was negligible.

In the potash series, its continued omission from plot 11 induced the expected reductions in yield. The results from the high-potash treatments of plots 8 and 9 are complicated by the fact both had received phosphate in their fertilizers previously, and on this account may have given higher yields for about five years than produced by the previously unfertilized check plots. The comparisons of 1939-1946, however, can be considered as free from this complication. During these years the increases on plots 8 and 9 were so small as to be of very questionable significance. In other words, it is doubtful if more than 80 pounds of potash per acre, as supplied by the 8-12-8 of plot 10, was needed by tomatoes. Preference for this interpretation comes from the fact that during 1923-29, the fertilizer supplying only 50

Table 7. Yield of Tomatoes on Limed Plots, 1915-29

Plot	Annual Application*	Fertilizer per acre, lb.		Average annual yield per acre, lb.		Increase over unfertilized checks, lb.	
		1915-22	1923-29	1915-22	1923-29	1915-22	1923-29
	North Block, check plots limed the same as all others						
15	Nitrate of soda	160	320	9,128	7,994	444	980
12	Sulfate of ammonia	†	240	9,778	7,434	445	151
11	Superphosphate, 16%	400	800	11,345	8,551	1,590	821
9	4-10-0	625	1,250	11,480	10,314	1,217	1,991
8	4-10-4	625	1,875	11,913	11,271	1,563	2,801
6	4-10-4	1,250	1,250	13,138	11,834	2,733	3,110
3	Manure			13,803	12,896	3,512	3,881
2	Manure and superphos.	400	800	14,485	13,180	4,245	3,967
	South Block, check plots not limed						
33	None, except lime			6,715	5,820	622	—36
36	Superphosphate, 16%	400	400	7,771	6,646	1,634	414
34	4-10-0	625	625	9,153	8,163	3,037	2,183
31	4-10-4	625	625	9,128	9,819	2,448	3,559
25	Manure			13,663	12,237	5,571	5,013
28	Manure and superphos	400	400	13,743	12,707	5,951	5,415
26	Manure and 4-10-0	625	625	13,377	13,794	5,585	6,547

* All manure applications at rate of 16 tons per acre

† Mixture of sulfate of ammonia, 65 pounds, and nitrate of soda, 80 pounds per acre.

Table 8. Yield of Tomatoes, 1931-46

Fertilizer applied before planting at rate of 1000 pounds per acre; side dressings of sulfate of ammonia at rate of 190 pounds per acre

Plot	Fertilizer Before Planting Formula	Fertilizer Side Dressings No.	Average annual yield per acre 1931-38 Lb.	Average annual yield per acre 1939-46 Lb.	Increase or decrease compared with uniformly fertilized check plots 1931-38 Lb.	Increase or decrease compared with uniformly fertilized check plots 1939-46 Lb.
			Fertilizers without Manure			
			Nitrogen Series			
36	0-12-8		6,879	9,618	—1,205	—2,407
15	8-12-8		9,318	13,698	353	751
14	8-12-8	1	9,107	13,045	— 59	11
13 ck.	8-12-8	2	9,367	13,120		
12	8-12-8	3	9,475	13,100	349	— 118*
			Phosphate Series			
31	8-0-8	2	8,526	10,965	88	— 705
32 ck.	8-12-8	2	8,213	11,955		
34	8-20-8	2	8,778	12,133	651	130
			Potash Series			
11	8-12-0	2	7,964	11,950	— 865	—1,367
10 ck.	8-12-8	2	8,533	13,415		
9	8-12-16	2	9,183	13,830	651	360
8	8-12-24	2	9,455	13,678	924	152
			Fertilizers with 8 tons of Manure per acre			
			Nitrogen Series			
2	0-8-0		10,914	14,340	1,666	637
26	8-8-0		10,468	13,275	1,600	1,622
3	8-8-0	2	10,947	14,655	1,689	708
			Phosphate Series			
25	8-0-0		9,790	13,253	937	1,416
26	8-8-0		10,468	13,275	1,600	1,622
24	8-16-0		10,280	13,290	1,436	1,268
23	8-24-0		10,611	13,588	1,775	1,382
			Fertilizers with 16 tons of Manure per acre			
27	none		9,551	11,960	682	491
28	8-6-4		10,666	13,178	1,788	1,894
5	8-8-0	3	10,300	15,485	1,278	1,498
			Rate of Application of 8-12-8, without Manure			
	Lb. per acre					
33	none		4,755	8,095	—3,415	—3,883
30	500		8,203	10,708	— 459	— 677
29	1000	2	8,887	11,100		
6	1500	2†	9,764	13,400	988	— 383*
	Least significant difference				818	1,352

* Decline in yield presumed to be due to acidity of soil.

† Side dressings of 285 pounds per acre

pounds of potash gave as good yields as one supplying 75 pounds per acre.

In the rate-of-application series at the bottom of Table 8, the yields from 500 pounds of 8-12-8 are best compared with those of plot 15 in the nitrogen series, because it also received no side dressings. By this comparison the yields from 500 pounds were on the threshold of being significantly lower than from 1000 pounds per acre. The results from 1500 pounds on plot 6 are best compared with those from other previously well fertilized plots such as 8, 9, and 34. Judging from the increases over the checks, the average yield on plot 6 was slightly larger than that of these other plots during 1931-38. Again remembering the good yields from somewhat less fertilizer during preceding years, the writer is inclined to judge the small differences during 1931-38 as being negligible. In other words, the 1500 pounds of 8-12-8 on plot 6 was not superior to the 1000 pounds per acre mixtures of plots 8, 9 and 34. After 1938, the lower yield of plot 6 is presumed to be due to the increasing acidity of its soil.

According to this interpretation, the fertilizer needed by tomatoes on soil previously moderately fertilized is 1000 pounds per acre of 8-12-8, without side dressings of nitrogen fertilizer. Turning again to Table 8, one may note that this was the treatment of plot 15, and that the increase over its check during 1939-46 was not exceeded by that of other unmanured plot.

On soil previously unfertilized, the formula would need to be raised to 8-20-8, while on soil known to contain more than 200 pounds per acre of available phosphorus the proportion of phosphoric acid might be dropped to a formula of 8-4-8.

Finally, it should be re-emphasized that during 1923-29 the application of 1250 pounds of 4-10-4 per acre supplying only 50 pounds of nitrogen and of potash, gave as good yields as 1875 pounds. Fertilizers supplying only 50 pounds of nitrogen and of potash were not tested during the following years, hence there is no direct evidence here that more than 50 is needed. Moreover, as shown later in Table 16, a crop of 15,000 pounds of tomatoes removes less than 50 pounds of nitrogen and of potash. It seems necessary, then, to make two recommendations for tomatoes; a minimum equivalent to 1000 pounds of 5-12-5, and a maximum of 8-12-8. In both, the proportion of phosphoric acid may be modified as suggested above, if the available phosphorus in the soil is known to be high or low.

Fertilizers with Manure. During the early years of the experiment, (Table 7) a supplement of superphosphate on plots 2 and 28 resulted in small increases in yield over manure alone on plots 3 and 25. The addition of some nitrate of soda to the superphosphate of plot 26 induced no increase over plot 28 during 1915-22, but gave some during 1923-29. With the manure application reduced to eight tons per acre after 1930 (Table 8) the inclusion of phosphate on plots 26, 24, and 23 similarly produced small increases over plot 25, at least during 1931-38. The presence of sulfate of ammonia in the fertilizer of plot 26 was of no benefit (compared to plot 2) during 1931-38, but judging from increase over the checks it was of benefit in the last eight years. Side dressings of sulfate of ammonia on plot 3 were ineffective during 1931-38 and somewhat detrimental during the following period, just as they were on unmanured plots.

Where manure continued to be applied at the rate of 16 tons per acre there were significant increases from the supplemental fertilizer on plot 28. Judging from the appearance of the plants, the principal benefit was due to the nitrogen. If this is correct, it seems that nitrogen fertilizer was of more value with 16 tons of manure than with eight tons per acre. Additional nitrogen, applied as side dressing on plot 5, was of no benefit.

From these rather inconsistent data, it appears advisable to recommend some phosphate fertilizer with manure, at least on land that has not had phosphate previously. It is less certain that nitrogen fertilizer should be advised. In the last 16 years, only in seven seasons did the nitrogen fertilizer on plot 26 result in larger increases over the checks than appeared without nitrogen on plot 2. Moreover, in two seasons it was noticeably detrimental. If nitrogen fertilizer is to be used, smaller amounts seem preferable to the 380 pounds of sulfate of ammonia used here during the last 16 years. The small application of 160 pounds of nitrate of soda per acre, applied to plot 26 in the earlier years, gave fully as good results. Likewise the superphosphate supplying 64 pounds of phosphoric acid per acre as tested during the years, would probably prove ample with eight-ton applications of manure.

Results with Cucumbers

Cucumbers have been a difficult crop to handle accurately. The seedlings have often been injured by insects, necessitating some replanting. Losses from disease have varied from plot to plot. During the rush of harvest some injury to the vines has been unavoidable. With experimental errors larger than from the other crops, the data have been correspondingly more difficult to appraise.

Special value of manure. During the first eight years of the experiment excellent yields of cucumbers were obtained from complete fertilizer as well as from manure, but thereafter the manured plots frequently far outyielded the best of the fertilizer treatments. Very curiously, the benefit from manure was most conspicuous in unfavorable seasons when drouth or diseases prevailed. This is well illustrated by the comparative yields of plots 5 and 6 listed in Table 9. Of special interest, however, is the fact that in the two seasons of best yields the fertilizer gave fully as good crops as did the manure supplemented with fertilizer. In other words, when growing conditions were favorable the fertilizer applied to plot 6 supplied ample nutrients for bumper crops.

Fertilizer without manure. During the first eight years of the experiment (Table 10) 1250 pounds of 4-10-4 on plot 6 showed only a small increase over 625 pounds per acre on plot 8. When the rate was increased to 1875 pounds on plot 8 no increase appeared over the continued application of 1250 pounds on plot 6. Moreover, judging by the increase over the checks, neither of these heavy applications were appreciably superior to 625 pounds on plot 31. Another respect in which cucumbers differed from cabbage and tomatoes during the early years, was in the conspicuous reduction in yield after 1923 where potash was omitted from the fertilizer on plot 34. Potash de-

Table 9. Seasonal Differences in the Benefit from Manure on Cucumbers, 1931 - 1943

Seasons listed according to the yield of unmanured Plot 6

Season	Fertilizer only Plot 6	Manure and fertilizer Plot 5	Increase of Plot 5 over Plot 6	
	Yields in pounds per acre		Lb.	Percent
1937	25,760	22,960	—2,800	—10.9
1942	25,120	24,520	— 600	— 2 4
1941	19,080	19,640	560	2.9
1939	19,000	22,000	3,000	15.8
1938	13,280	14,560	1,280	9 6
1933	12,120	17,520	5,400	44.6
1932	9,440	14,040	4,600	48 7
1943	8,240	11,040	1,800	19.5
1940	8,860	9,640	780	8.8
1936	4,360	6,120	1,760	40.4
1931	3,480	5,200	1,720	49.4
1934	2,840	5,720	2,880	101.4
1935	2,720	6,120	3,400	125.0

ficiency became so acute that the yields were but little better than on the wholly unfertilized checks. At the same time there was but little evidence of deficiency where potash was similarly omitted from plot 9.

Turning to the data of the following years, attention may be first directed to the rate-of-application series at the bottom of Table 11. Five hundred pounds per acre of 8-12-8, on plot 30, did not give quite as good yields as 1000 pounds. The deficiency was of the same magnitude as shown by 625 pounds of 4-10-4 previously. Somewhat more fertilizer is, therefore, to be recommended.

Table 10. Yield of Cucumbers on Limed Plots, 1915 - 1929

Plot	Annual Application*	Fertilizer per acre, lb.		Average annual yield per acre, lb.		Increase over unfertilized checks, lb.	
		1915-22	1923-29	1915-22	1923-29	1915-22	1923-29
	North Block; check plots limed same as all others						
15	Nitrate of soda	160	480	16,295	10,360	2,009	1,284
12	Sulfate of ammonia	†	360	17,547	8,829	1,776	—900
11	Superphosphate, 16%	400	800	17,498	9,669	1,656	— 68
9	4-10-0	625	1,250	19,450	14,617	3,703	4,037
8	4-10-4	625	1,875	19,236	16,071	3,654	4,656
6	4-10-4	1,250	1,250	19,619	18,274	4,265	4,967
3	Manure			18,567	21,754	3,302	7,082
2	Manure and superphos.	400	800	19,340	21,629	4,034	7,709
	South Block; check plots not limed						
33	None, except lime			13,452	5,886	588	—1,156
36	Superphosphate, 16%	400	400	11,111	5,571	481	632
34	4-10-0	625	625	15,356	7,183	3,609	842
31	4-10-4	625	625	20,086	13,854	5,841	4,707
25	Manure			22,061	24,383	9,136	13,458
28	Manure and superphos.	400	400	23,528	23,703	10,603	12,006
26	Manure and 4-10-0	625	625	23,978	28,217	13,053	17,034

* All manure applications at rate of 16 tons per acre.

† Mixture of sulfate of ammonia, 65 pounds, and nitrate of soda, 80 pounds per acre.

In the nitrogen series of Table 11 the actual average yields indicate that the side dressings were successively beneficial, while the increases compared to the checks indicate that they were of very little benefit during 1931-38 and thereafter were actually detrimental. To throw further light on this question a side-dressing series was started anew in 1947 with irrigation. The side dressings proved to be detrimental (data unpublished). The writer is, therefore, inclined to accept the comparisons with the checks as the more reliable interpretation of the results, and conclude that the side dressings were ineffective and at times detrimental.

In the phosphate series, it was surprising to find 8-20-8 of plot 34 giving significantly higher average yield than the 8-12-8 of plot 32 during 1939-43. Examination of the data, year by year, showed that it was only in the last year, 1943, that the 8-12-8 was supplying ample phosphate. Thus it may be necessary to have a somewhat higher reserve of phosphate in the soil for cucumbers than for the other crops before the amount in the fertilizer can be reduced to an ordinary proportion.

In the potash series of Table 11, its omission from plot 11 resulted in conspicuously reduced growth and yield. In appraising the high-potash formulas of plots 9 and 8, it should be kept in mind that both had been well supplied with phosphate in previous years, hence their increases over plot 10 can be attributed to the presence of ample phosphate in their soil, as well as to the extra potash. With the gradual accumulation of phosphate in plot 10, the increase shown by plots 9 and 8 became less and less. The same reasoning holds for the results from plot 6 in the rate-of-application series at the bottom of Table 11. As there is some uncertainty as to whether the eight percent of potash in the fertilizer of the check plots was actually ample, at least when they were first fertilized, 12 percent is tentatively recommended for depleted soil, and eight percent for land that has been well fertilized for a few years.

The formulas derived from the data of the last 16 years, when expressed in terms of 1000-pound per acre, are thus 8-20-12 for depleted soil, and 8-12-8 for soil of more fertility. At the same time, from the good results of the earlier years with 1250 pounds of 4-10-4, it may also be recommended. Finally, as suggested in the introduction, if soil is known to contain more than 200 pounds per acre of available phosphorus, the proportion of phosphoric acid may be reduced to give formulas of 8-4-8, or 5-4-5, if applied at the rate of 1000 pounds per acre. This complex array of recommendations will be found more simply classified in the summary of the recommendations, where suggestions are also made on how to obtain them from currently approved grades of fertilizers.

Fertilizers with manure. In the first eight years of the experiment (Table 10) a supplement of superphosphate on plots 2 and 28 produced slightly larger yields than the manure alone on plots 3 and 25. This slight benefit did not appear during 1923-29. The addition of nitrate of soda, however, gave a large increase on plot 26 at this time.

Table 11. Yield of Cucumbers, 1931-1943

Fertilizer applied before planting at rate of 1000 pounds per acre, side dressings of sulfate of ammonia at rate of 190 pounds per acre

Plot	Fertilizer Before Planting Formula	Fertilizer Side Dressings No.	Average annual yield per acre 1931-38 Lb.	Average annual yield per acre 1939-43 Lb.	Increase or decrease compared with uniformly fertilized check plots 1931-38 Lb.	Increase or decrease compared with uniformly fertilized check plots 1939-43 Lb.
			Fertilizers without Manure			
			Nitrogen Series			
36	0-12-8		4,583	8,776	— 430	—2,472
15	8-12-8		6,345	14,152	— 385	2,432
14	8-12-8	1	7,260	14,688	120	1,176
13 ck	8-12-8	2	7,550	15,304		
12	8-12-8	3	7,995	15,864	468	365
			Phosphate Series			
31	8-0-8	2	6,723	10,944	306	—2,456
32 ck	8-12-8	2	5,415	12,960		
34	8-20-8	2	6,035	13,952	888	2,133
			Potash Series			
11	8-12-0	2	4,530	11,564	—2,974	—4,129
10 ck	8-12-8	2	7,480	15,888		
9	8-12-16	2	9,098	16,272	1,378	443
8	8-12-24	2	9,421	15,960	1,463	190
			Fertilizer with 8 tons of Manure per acre			
			Nitrogen Series			
2	0-8-0		11,853	18,748	4,480	3,736
26	8-8-0		13,775	17,464	5,482	3,213
3	8-8-0	2	10,208	17,696	2,328	1,872
			Phosphate Series			
25	8-0-0		14,235	17,504	5,984	3,263
26	8-8-0		13,775	17,464	5,482	3,213
24	8-16-0		13,465	18,272	5,256	4,041
23	8-24-0		11,810	16,904	3,643	2,682
			Fertilizer with 16 tons of Manure per acre			
27	none		14,360	16,912	6,024	2,651
28	8-6-4		12,880	17,688	4,509	3,418
5	8-8-0	3	11,530	17,368	3,093	1,040
			Rate of Application of 8-12-8, without Manure			
	Lb. per acre					
33	none		1,988	7,784	—3,293	—4,605
30	500		6,680	13,264	— 738	— 576
29 ck	1,000	2	8,420	14,280		
6	1,500	2*	9,250	16,260	937	240
Least significant difference					1,888	2,078

* Side dressings 285 pounds per acre

In Table 11, the inclusion of nitrogen in the fertilizer of plot 26 did not consistently increase yield when compared with plot 2, and the side dressings of plot 3 were often detrimental. Likewise, with 16 tons of manure per acre, the side dressings of plot 5 proved detrimental. Incidentally, these results tend to confirm the deduction drawn from the treatments without manure—side dressings of nitrogen fertilizer are likely to be detrimental on cucumbers. On the other hand, the small and inconsistent benefit from the nitrogen fertilizer applied before planting since 1930 is at variance with the good results of 1923-29. Perhaps the amount applied since 1930 has been too large, or perhaps sulfate of ammonia used since then was not as effective as the nitrate of soda used previously. Whatever the explanation, the best nitrogen supplement during the course of the experiment was 160 pounds per acre of nitrate of soda included in the fertilizer of plot 26 prior to 1931.

If the results from the phosphated plots of Table 11 are averaged as a group, they show no increase over the yield of plot 25.

Finally, since manure has proved to be of special value for cucumbers on this soil, it is important to note that the general average yield from eight tons per acre (Table 11) has been equal to that from the plots which continued to get 16 tons. Moreover, on soil which has been manured for several years, or is otherwise known to be of fairly high level of fertility, the only supplement likely to be needed with eight tons of manure per acre is a relatively small amount of nitrogen fertilizer, such as 160 pounds of nitrate of soda per acre.

Results with Sweet Corn

During the eight years of 1931-38, there was one complete crop failure of sweet corn and three other seasons when yields were reduced by drouth. In the following eight-year period the crops were more or less infested with corn borer and ear worm. As a whole, the average yields of the last 16 years were below the level of good production.

Fertilizers without manure. At the outset (Table 12), the limed check plots of the North Block, as well as plot 33, averaged over 7000 pounds of sweet corn per acre. With yields of this magnitude on unfertilized plots, none of the fertilizers increased yields enough to much more than pay for its cost (7). During 1923-29 the continued omission of fertilizers resulted in a decline in average yield to about 6,000 pounds per acre. At the same time the nitrogen fertilizers on plots 12 and 15 proved as effective as any fertilizer mixtures.

In the last 16 years (Table 13) the continued omission of fertilizer on plot 33 significantly reduced the yield below that of the now fertilized check plots. Moreover, 500 pounds per acre of 8-12-8 on plot 30 was clearly insufficient and the appearance of the plants indicated that they were suffering from nitrogen deficiency, just as where nitrogen was omitted on plot 36.

Table 12. Yield of Sweet Corn on Limed Plots, 1915-1929

Plot	Annual Application*	Fertilizer per acre, lb.		Average annual yield per acre, lb.		Increase over unfertilized checks, lb.	
		1915-22	1923-29	1915-22	1923-29	1915-22	1923-29
	North Block; check plots limed the same as all others						
15	Nitrate of soda	160	320	7,580	7,331	309	995
12	Sulfate of ammonia	†	240	7,525	8,206	206	1,602
11	Superphosphate, 16%	400	800	7,775	6,891	464	232
9	4-10-0	625	1,250	8,055	7,131	800	364
8	4-10-4	625	1,875	7,840	7,069	635	248
6	4-10-4	1,250	1,250	8,115	8,023	870	797
3	Manure			7,960	9,263	503	1,421
2	Manure and superphos.	400	800	7,960	9,023	471	1,271
	South Block; check plots not limed						
33	Lime only			7,415	6,343	910	511
36	Superphosphate, 16%	400	400	6,360	6,080	245	391
34	4-10-0	625	625	7,560	6,897	1,250	1,112
31	4-10-4	625	625	8,075	7,360	1,270	1,324
25	Manure			8,765	10,097	2,253	3,934
28	Manure and superphos.	400	400	9,135	9,589	2,623	3,287
26	Manure and 4-10-0	625	625	8,870	9,777	2,358	3,568

* All manure applications at rate of 16 tons per acre.

† Mixture of sulfate of ammonia, 65 pounds, and nitrate of soda, 80 pounds per acre.

The inclusion of eight percent of nitrogen in the fertilizer mixture of plot 15 surprisingly failed to overcome the deficiency in most of the years between 1931 and 1938. It was the first and third side dressing of sulfate of ammonia that proved effective. In contrast, during the last eight years, the initial fertilizer supplied ample, or nearly ample, nitrogen. From these divergent results, it is impossible to formulate a definite rule for economically and effectively supplying the nitrogen for sweet corn. When to side dress remains largely a matter of judgment. On the other hand, 80 pounds of nitrogen per acre, applied to most of the plots since 1930, may have been more than needed. Equally good results were obtained from 50 pounds during 1923-29. The broad recommendation, then, is to apply 50 to 80 pounds of nitrogen per acre before planting and to side dress once or twice in wet seasons, when it is deemed more nitrogen may be needed.

Table 13. Yield of Sweet Corn, 1931-46*

Fertilizers applied before planting at rate of 1000 pounds per acre; side dressings of sulfate of ammonia at rate of 190 pounds per acre

Plot	Fertilizer Before Planting Formula	Fertilizer Side Dressings No.	Average annual yield per acre 1931-38 Lb.	Average annual yield per acre 1939-46 Lb.	Increase or decrease compared with uniformly fertilized check plots 1931-38 Lb.	Increase or decrease compared with uniformly fertilized check plots 1939-46 Lb.
Fertilizers without Manure						
			Nitrogen Series			
36	0-12-8		3,446	2,710	—1,634	—2,020
15	8-12-8		5,114	6,670	—1,124	— 495
14	8-12-8	1	5,726	6,810	— 213	— 400
13 ck	8-12-8	2	5,640	7,255		
12	8-12-8	3	6,434	6,835	783	— 34
			Phosphate Series			
31	8-0-8	2	5,583	4,545	84	—1,045
32 ck	8-12-8	2	5,160	5,560		
34	8-20-8	2	5,337	4,800	230	— 206
			Potash Series			
11	8-12-0	2	4,891	5,535	— 771	— 946
10 ck	8-12-8	2	5,674	6,095		
9	8-12-16	2	5,714	6,360	491	333
8	8-12-24	2	4,983	5,890	— 121	— 68
Fertilizer with 8 tons of Manure per acre						
			Nitrogen Series			
2	0-8-0		6,874	5,220	450	— 401
26	8-8-0		8,126	6,805	2,047	1,314
3	8-8-0	2	7,217	6,710	865	961
			Phosphate Series			
25	8-0-0		7,829	6,635	1,782	1,096
26	8-8-0		8,126	6,805	2,047	1,314
24	8-16-0		7,549	6,345	1,535	961
23	8-24-0		7,794	6,065	1,813	733
Fertilizer with 16 tons of Manure per acre						
27	none		7,537	6,845	1,425	1,301
28	8-6-4		8,109	6,670	1,964	1,072
5	8-8-0	3	7,737	7,015	1,889	1,135
Rate of Application of 8-12-8, without Manure						
	Lb. per acre					
33	none		3,171	2,830	—1,962	—2,454
30	500		4,269	3,760	—1,569	—1,860
29 ck	1,000	2	6,177	5,650		
6	1,500	2**	6,628	5,965	1,213	80
Least significant difference					1,298	1,312

* Not including 1936 when crop failed due to drouth.
** Side dressings of 285 pounds per acre.

In the phosphate series of Table 13, the reserve in the soil of plot 31 supplied the needs of sweet corn through 1940. Similarly, during the first 16 years (Table 12) there was little or no indication of deficiency where nothing but nitrogen fertilizer was supplied on plots 12 and 15. Moreover, when 8-12-8 was first applied to check plot 32 in 1931, it gave as good yields as the 8-20-8 on plot 34. In its capacity to obtain its needed phosphate from the soil, sweet corn differed from the other crops of this experiment. Consequently, if ample phosphate is supplied to other crops grown in rotation with sweet corn, the level of available phosphate in the soil is likely to be maintained at a point where no phosphate will be needed in the fertilizer applied to the corn. On depleted soil the maximum to be recommended from the results here is 120 pounds of phosphoric acid per acre.

In the early years of the experiment (Table 12), the inclusion of potash in the fertilizers of plots 6 and 8 resulted in little or no increase over plot 9, and this was duplicated in the comparison of plots 31 and 34. After 1930 (Table 13), the continued omission of potash from plot 11 noticeably reduced the size of plants and resulted in some reduction in average yields. From the results of the early years, one might conclude that if sweet corn was grown in rotation with other crops that were fertilized, potash could also be omitted from its fertilizer. As shown later, however, in Table 16, the potash applications recommended for cabbage and tomatoes are no larger than the amounts removed by good crops. Hence, no accumulation of potash in the soil, such as occurs with phosphate, could be expected. It would seem safer, therefore, to also give sweet corn a maintenance amount of potash. If only the ears were harvested, the amount removed would be only 20 pounds per acre. If the stover were also harvested, the amount would be about 55 pounds. In support of a tentative recommendation of 50 pounds of potash per acre the sustained good yield on plot 6 during the first 15 years may be cited—its fertilizer supplied 50 pounds of potash per acre.

In conclusion, nitrogen is the important fertilizer constituent needed by sweet corn on this soil. If supplied by sulfate of ammonia, 240 to 380 pounds per acre are advised before planting, to be followed by one or two side dressings if deemed needed. On soil maintained at a suitable level for other vegetable crops, no phosphate is advised. The recommended application of potash would be supplied by 100 pounds per acre of muriate of potash.

Fertilizers with manure. In the early years (Table 12) the inclusion of nitrogen in the supplement of plot 26 did not materially increase the yield over that of plot 28. Likewise, with continued application of 16 tons of manure per acre (Table 13) the complete fertilizer of plot 28 did not result in consistent increase over the manure alone of plot

27. With eight tons per acre, however, the inclusion of nitrogen in the supplement of plot 26 increased the yield over that of plot 2. From a practical viewpoint, the fact that nitrogen fertilizer was not needed with 16 tons manure may be taken as an indication that somewhat less than the 80 pounds per acre tested here would have sufficed with eight tons of manure per acre. Since 50 pounds is suggested here for unmanured soil 50 pounds of nitrogen per acre would probably also be ample with manure. Additional nitrogen, applied as side dressings on plot 3, was ineffective.

In the group of phosphate treatments of Table 13, the general average yield from the phosphated plots did not exceed that from plot 25. Hence, the regular application of eight tons of manure per acre supplied the phosphate needed by sweet corn.

Sixteen tons of manure per acre, supplemented with fertilizer, on plots 5 and 28 gave very small increases over the eight tons per acre of plot 26. From a practical viewpoint, if manure were available, not more than eight tons per acre is to be recommended.

SUMMARY OF THE RECOMMENDATIONS

To make effective use of the recommendations given here it is necessary to know fairly reliably the amount of available phosphorus in a soil. Available phosphorus determinations by quick tests have not proved accurate enough (3), and Truog's method (15), commonly used for scientific analyses, is too tedious for routine soil testing service. In recent years, procedures of suitable accuracy have been developed and adopted by agencies charging a fee for soil testing. The

Table 14. Amount of Fertilizer Nutrients Recommended for Soils at Three Different Levels of Fertility

	Pounds per acre to be applied before planting								
	For soil well fertilized previously						For soil not well fertilized previously		
	Containing more than 200 pounds of available phosphorus per acre			Containing less than 200 pounds of available phosphorus per acre					
	Nitrogen	Phos. acid	Potash	Nitrogen	Phos. acid	Potash	Nitrogen	Phos. acid	Potash
Cabbage	80	40	120	80	120	120	80	200	120
Tomatoes	50-80	40	50-80	50-80	120	50-80	50-80	200	80
Cucumbers	50-80	40	50-80	50-80	120	50-80	80	200	120
Sweet corn	50	none	50	50	none	50	50	120	50

amount of phosphorus determined by these new methods, however, may differ considerably from the amount determined by Truog's procedure. For example, Bray's method as used in Illinois (2) on soil from this experiment showed 30 to 60 percent more than did Truog's method. When some newer method becomes available to Ohio growers, the value it shows which corresponds to Truog's 200-pound level needs to be known. Then for practical use, this value can replace the 200-pound threshold in Tables 14 and 15.

Fertilizers Needed Without Manure

In the preceding pages the fertilizers recommended are expressed in terms of formulas to be applied at the rate of 1000 pounds per acre. As most of these formulas are not commonly available, the recommendations are first summarized in Table 14 in terms of the amount of each fertilizer nutrient to apply per acre. Then, in Table 15, suggestions are offered on how these nutrients can be supplied by starting with currently approved Ohio grades of fertilizers, and supplementing with basic fertilizer materials.

If the fertilizer is to be applied by drilling before planting, as it was in this experiment, the middle group of recommendations is suit-

Table 15. Fertilizer Combinations Which Approximately Meet the Recommendations

A. Fertilizers needing supplements of superphosphate or of potash

	Mixed fertilizer or material Formula	Mixed fertilizer or material Lb. per acre	Superphosphate, 20% Lb. per acre	Muriate of potash, 50% Lb. per acre	Nutrients supplied,* Lb. per acre
	For soil well fertilized previously, containing more than 200 pounds of available phosphorus per acre				
Cabbage	10-6-4	800		180	80-48-120
Tomatoes**	10-6-4	800		100	80-48-82
Cucumbers	8-8-8	625			50-50-50
Sweet corn	Sulfate of ammonia	250		100	50-0-50
	For soil well fertilized previously, containing less than 200 pounds of available phosphorus per acre				
Cabbage	8-8-8	1000	200	80	80-120-120
Tomatoes	8-8-8	1000	200		80-120-80
Cucumbers	8-8-8	625	350		50-120-50
Sweet corn	Sulfate of ammonia	250		100	50-0-50
	For soil not previously fertilized				
Cabbage	8-8-8	1000	600	80	80-200-120
Tomatoes	8-8-8	1000	600		80-200-80
"	4-12-8	1250	250		50-200-100
Cucumbers	8-8-8	1000	600	80	80-200-120
Sweet corn	8-8-8	625	350		50-120-50

* Expressed in the sequence of nitrogen-phosphoric acid-potash, for comparison with the recommendations as listed in Table 14.

** Two different recommendations are made for tomatoes for each soil condition. Where bracketed with cucumbers, the same two recommendations apply for cucumbers.

Table 15 (continued)

B. Fertilizers needing supplements of sulfate of ammonia or other nitrogen fertilizer

	Mixed fertilizer or material Formula	Mixed fertilizer or material Lb. per acre	Sulfate of ammonia*** Lb. per acre	Nutrients supplied, Lb. per acre
	For soil well fertilized previously, containing more than 200 pounds of available phosphorus per acre			
Cabbage	0-9-27	450	400	80-40-120
Tomatoes / Cucumbers	3-9-18	450	330	80-40-80
Tomatoes / Cucumbers	8-8-8	625		50-50-50
Sweet corn	Muriate of potash	100	250	50-0-50
	For soil well fertilized previously, containing less than 200 pounds of available phosphorus per acre			
Cabbage	5-10-10	1200	100	80-120-120
Tomatoes / Cucumbers	4-12-8	1000	200	80-120-80
Tomatoes / Cucumbers	4-12-8	625	125	50-100-50
Sweet corn	Muriate of potash	100	250	50-0-50
	For soil not previously well fertilized			
Cabbage	4-16-8	1500	100	80-240-120
Tomatoes	4-16-8	1000	50 or 200	50 or 80-160-80
Cucumbers	4-16-8	1500	100	80-240-120
Sweet corn	4-16-8	625	125	50-100-50

*** In order to deal in rounded numbers, the nitrogen content of sulfate of ammonia is calculated as 20 per cent, whereas its guaranteed analysis is commonly 20.8 per cent.

able for soils with 150 to 200 pounds of available phosphorus per acre. But if the mixed fertilizer is to be applied along the row, its phosphate would be expected to be more available to the young plants and these recommendations might prove ample for soil with somewhat less than 150 pounds of available phosphorus per acre.

Two listings of recommendations are given in Table 15. In part "A," the mixed fertilizers selected are ones with a high proportion of nitrogen. Therefore, in most cases, they need to be supplemented with phosphate or potash, or both. In part "B," the mixed fertilizers are those with approximately the desired ratio of phosphoric acid to potash, and these need only a supplement of nitrogen, such as would be supplied by the sulfate of ammonia listed.

As supplements are thus needed in most instances, the practical question may be raised: Can the supplements be applied before plowing? Plowing down of nitrogen fertilizer is currently recommended for sweet corn (10), and often suggested for other crops. As it was not tested in this experiment, however, no definite recommendation is made here.

Another procedure for obtaining the fertilizer combinations is to have them mixed to order. Any manufacturer engaged in custom mixing should be able to formulate the proper mixtures from the list of nutrients as given in Table 14. Custom mixtures have the obvious advantage of applying all the fertilizer in a single operation. Where applied with an attachment to the planter they may, in some instances, prove more effective, as well as more economical to handle, than any of the double combinations listed in Table 15. For those who may wish to try some of the recommendations on a small scale, the mixtures can be easily made at home. For example, the equivalent of 1000 pounds of 8-4-12, as recommended for cabbage on soil with over 200 pounds of available phosphorus per acre, has often been mixed at the Experiment Farm from:

385 pounds, sulfate of ammonia
200 pounds, 20 percent superphosphate
240 pounds, 50 percent muriate of potash

Made without any filler, this mixture has kept in good condition for several weeks, and has been easy to apply either drilled or with a planter attachment.

Side dressing. The only material recommended here for side dressing is one supplying nitrogen. For early cabbage, soon after the plants are well started, a large side dressing of about 300 pounds per acre of sulfate of ammonia, or its equivalent of some other material, such as nitrate of soda or ammonium nitrate, is important. In some seasons a second application may be needed. For sweet corn, one or two smaller side dressings are advised for cool, wet seasons. On the other hand, side dressings of tomatoes and cucumbers has proved detrimental more often than beneficial, hence it is not advised for these two crops.

Table 16. Estimate of the Fertilizer Nutrients Removed by the Crops

All calculations in pounds per acre

	Assumed weight of good crop	Nutrients in the harvested crop			Nutrients in minimum fertilizer recommended*		
		Nitrogen	Phos. acid	Potash	Nitrogen	Phos. acid	Potash
Cabbage, heads	33,000	150	20	140	140	40	120
Tomatoes, fruits	15,000	30	10	44	50	40	50
Cucumber, fruits	24,000	30	15	30	50	40	50
Sweet corn, ears	10,000	35	6	20	50	none	50
Stover	10,000	30	7	38			
Total for four crops		275	58	272	290	120	270

* Including the nitrogen in one 285-pound side dressing of sulfate of ammonia on cabbage.

Fertilizers Needed With Manure

With manure the only fertilizer recommended for all four crops grown here is one supplying nitrogen. For cabbage, sulfate of ammonia, applied at the high rate of 380 pounds per acre, is recommended before planting. For the other crops, smaller amounts of nitrate of soda are recommended: for tomatoes and cucumbers 160 pounds per acre, and for sweet corn 320 pounds.

If cabbage is expected to yield over 30,000 pounds per acre it may also need a side dressing of sulfate of ammonia at the rate of 200 pounds per acre.

On soil regularly manured, or previously well phosphated, the use of superphosphate is not advised for any of the crops. At a lower level of fertility, however, superphosphate supplying 64 pounds of phosphoric acid per acre is recommended for cabbage and for tomatoes.

DISCUSSION

Recommended Fertilizers Compared With the Fertility Removed by the Crops

The amounts of fertilizer recommended here for fertile soil are much smaller than ordinarily applied to truck crops. The question, then, may be raised as to whether they supply as much nutrient as is removed in the harvested crops. None of the crops grown in this experiment were analyzed chemically, but numerous analyses are to be found in the literature. From an average of these analyses, as compiled by Winton and Winton (16), the amount removed by reasonably good crops can be estimated, as given in Table 16.

The interesting point in Table 16, is that the nitrogen and potash supplied in the recommended fertilizers closely balances that removed by the crops. And in spite of the small proportion of phosphoric acid in these minimum recommendations, it is twice as much as removed, when the four crops are averaged, or considered as a group.

General Principles of Supplying Fertility for Vegetable Crops

The results from this experiment, and recommendations derived, follow general principles that probably have broad application.

The first is that on loam and sandy loam it is possible and feasible to establish a reserve of phosphate ample for plant roots throughout the whole plowed layer. Indications here are that it is difficult to insure an ample supply of phosphate unless this reserve is present. The presence of an ample reserve can be detected by suitable soil analysis.

Incidentally, the maintenance of highly soluble phosphate in the soil might be expected to be wasteful, because part of it might be lost by leaching into the subsoil. A study of this possibility disclosed no evidence of such loss from the soil in this experiment (4). When suitable tests for available phosphate become commonly available, a procedure may be adopted like the one long followed in liming—relatively large quantities of phosphate fertilizer being applied until the amount available in the soil reaches the desired level, followed thereafter by relatively small maintenance applications.

The second general principle is that crops differ distinctly in their nitrogen requirement and in their sensitivity to excess. Sensitivity to excess nitrogen has been better demonstrated by experience on muck soil than by data here. Usually when the fruit or seeds are harvested, as tomatoes, melons, or beans, the crop is not fruitful on soil with an abundance of nitrogen. Sweet corn is an exception. On the other hand, if the vegetative portions of the plant are used as with cabbage, celery, potatoes or onions, the plants thrive on the large amounts of available nitrogen in muck soil. As a whole, then, nitrogen fertilizer needs to be applied in conformity with the requirement and the tolerance of the individual crop.

The principle in applying potash, at least on previously well fertilized soil, is to approximate the amount likely to be removed in the harvest crop.

Table 17. Yields From Large and From Moderate Application of Superphosphate Supplementing Manure

Data of 1939-46

Plot	Phos. acid applied per acre	Avail phos. in soil 1946	Average annual yield and increase over checks, lb. per acre							
			Cabbage		Tomatoes		Cucumbers		Sweet Corn	
	lb.	lb.	Yield	Inc.	Yield	Inc.	Yield	Inc.	Yield	Inc.
26	80	320	31,965	805	13,275	1,622	17,464	3,213	6,805	1,314
23	240	730	31,770	824	13,588	1,382	16,904	2,682	6,065	732
Increase from large application			—195	19	313	—240	—560	—531	—740	—582

Is excess phosphate in the soil detrimental? On sandy "old tobacco land" in Connecticut, Morgan and Jacobson (11) found that potato yields were significantly depressed when fertilizer with a large proportion of phosphate was applied. At the termination of their experiment the high-yielding, no-phosphate plots had 192 pounds of available phosphorus per acre. On the other hand, on soils with over 300 pounds per acre in North Carolina (reported as 710 pounds or more of P_2O_5) no detrimental effect was noted from phosphate in the fertilizer, (9).

In the present experiment the highest phosphate level was in plot 23, where eight tons of manure was supplemented with 8-24-0 at the rate of 1000 pounds per acre. Although the yields of the last eight years averaged slightly lower than where the supplement was 8-8-0 on plot 23 (Table 17), in no instance did the decrease approach statistical significance. Thus the data here agree with that from North Carolina in showing that excess phosphate in fertilizer applied to soil that already has an excess may not be appreciably detrimental.

GENERAL SUMMARY

A fertilizer experiment with early cabbage, tomatoes, cucumbers, and sweet corn was conducted for 32 years at the Washington County Truck Crops Experiment Farm, located in southeastern Ohio. The soil ranged from Chenango loam to fine sandy loam. The crops were grown every year and in rotation. The aim of the experiment was to aid growers in their fertilizer practices. The prinicpal data reported are the eight-year average yields of marketable produce.

The initial plan of the experiment, somewhat exploratory in nature, was followed for 16 years, then revised principally to test rather large applications of fertilizer.

Following this revision, the most unexpected result was the maintenance of good yields on a plot where phosphate was omitted from the fertilizer. Soil samples, collected at the time of revision, analyzed for readily available phosphorus by Truog's procedure, showed that the soil of this plot had 180 pounds per acre. After reviewing the literature reporting similar results, the conclusion is drawn that in general soils with 200 pounds of available phosphorus per acre have sufficient phosphate for all vegetable crops that have been thus studied. Correspondingly, the recommendation is advanced that on such soil the proportion of phosphate in the fertilizer be reduced to what is termed a "maintenance application"—about 30 to 40 pounds of phosphoric acid per acre annually.

At the same time, following the revision of the plan, previously unfertilized plots, with soil testing about 120 pounds of available phosphorus, were not amply supplied with phosphate when a mixture with 120 pounds of phosphoric acid per acre was drilled prior to planting.

Widely divergent recommendations are correspondingly made. Expressed in terms of pounds of each nutrient per acre, the recommended composition of fertilizers to apply ahead of planting are summarized in Table 14. Many of the mixtures recommended cannot be filled from currently approved fertilizer formulas. Therefore suggestions are made (Table 15) on how to supplement the Ohio grades to meet the recommendations.

Additional nitrogen applied as side dressing was needed regularly by cabbage, at times by sweet corn, but was at times detrimental to tomatoes and cucumbers.

For soil with a sufficiency of available phosphate the fertilizer should supply approximately the estimated amount of nutrients removed in the harvest crops (Table 16). The fertilizer thus recommended for fertile soil is distinctly different and considerably less in amount than commonly recommended.

Manure applied annually at the rate of eight tons per acre needed a supplement of nitrogen fertilizer only.

Manure thus supplemented produced on the average about seven percent higher yields than the best of the fertilizers on unmanured soil.

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